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# Mirror Material Properties Compiled for Preliminary Design of the Next Generation Space Telescope (30 to 294 Kelvin)

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## **TECHNICAL MEMORANDUM**

### **MIRROR MATERIAL PROPERTIES COMPILED FOR PRELIMINARY DESIGN OF THE NEXT GENERATION SPACE TELESCOPE (30 to 294 KELVIN)**

#### **1. INTRODUCTION**

In February 1996, the Program Development Directorate at NASA Marshall Space Flight Center (MSFC) began studying the feasibility of a Next Generation Space Telescope (NGST) and developed the prephase A program for it. After finishing some initial studies and concepts development work on the NGST,<sup>1</sup> Program Development handed this work to the Observatory Projects Office at NASA MSFC. NASA Goddard Space Flight Center (GSFC) was later given leadership of the NGST program.<sup>2</sup> NASA GSFC then issued a Cooperative Agreement Notice in April 22, 1996, to solicit proposals from industry to join in feasibility assessments related to the development of an NGST.<sup>3</sup> On August 19–21, 1996, “teams led by Lockheed Martin, TRW, and the GSFC concluded that an NGST was not only feasible and affordable, but that it could be made powerful using recent breakthroughs in space technologies.”<sup>4</sup>

##### **1.1 Mirror Material Tasks**

From April 1996 to June 1997, the Optical Telescope Assembly (OTA) materials team performed a number of tasks for the prephase A (Advanced Studies) design of the NGST, including (1) identifying viable mirror material candidates, (2) identifying valid comparison factors, (3) compiling an initial mirror material properties database, (4) trading and comparing the materials, and (5) identifying critical issues and concerns.

##### **1.2 Scope of This Report**

This NASA technical memorandum reports on the mirror material properties that were compiled from April 1996 to June 1997 for preliminary design of the NGST. This work was performed by the Preliminary Design Office and Materials & Processes Laboratory at NASA MSFC for the NGST OTA team which was led by John T. Humphreys, manager of the AXAF Telescope Office at NASA MSFC, in support of NASA GSFC.

## 2. MIRROR MATERIAL PROPERTIES THAT ARE CITED

Refer to appendices A through I for detailed mirror material properties.

### 2.1 Literature Survey

Several sources were consulted for mirror material property data—textbooks; Internet databases; Redstone Scientific Information Center (RSIC) databases, including NASA RECON, DTIC, and CPX WEB; and industrial suppliers of the mirror materials. Information from at least 6 industrial suppliers, 16 textbooks, 44 technical papers, and 130 abstracts were reviewed for mirror material property information.

### 2.2 Overview

Requirements from NASA GSFC, the lead center for the NGST study, specify a “scientific requirement for telescope temperatures in the range 40 to 60 K.”<sup>5</sup> Table 1 identifies the *lowest* temperature at which mirror material properties data was found during our survey of literature, the Internet, and industrial suppliers. Overall, the expected temperature range of the NGST is approximately 30 to 300 K.

Table 1. Lowest temperature at which material properties data is cited.

Type	Optical Material	Abbrev.	Lowest Temperature (K) at Which Data is Available							
			Density	CTE	k	Cp	E	Poisson's	YTS	UTS
Metal	Be Spherical Powder									
	Beryllium I-70A	Be I-70A	10°	10°	10°	20°	10°	10°	Room	Room
	Beryllium O-50	Be O-50	10°	5°	10°	20°			Room	Room
	Pure Nickel	Ni	Room	24°	24°	20°	20°	Room	Room	Room
	Electrodeposited Nickel	EdNi	Room	Room	30°	30°	Room	Room	78°	78°
Glass	Boro Silicate	Boro Si								
	Fused Silica Glass	SiO <sub>2</sub> (pc)	Room	Room	100°	150°	Room	Room		
	Fused Quartz, GE 214	SiO <sub>2</sub> (c)	Room	Room	Room	Room	Room	Room	Room	
	ULE 7971	ULE	Room	198°	223°	Room	73°	73°		
	Zerodur M	Zerodur	Room	75°	Room	Room	50°	Room		
Ceramic	CVD Silicon Carbide™	CVD SiC™	123°	133°	123°	123°	273°	Room	133°	
	Reaction-Bonded SiC	RB SiC								
Composite	Carbon/ Silicon Carbide	C/SiC	Room	4***	Room	Room	Room	Room		Room

Unfortunately, low temperature properties for many of the mirror substrate materials were not found in the literature surveyed up to June 1997. The property information cited in literature was typically at room temperature. Refer to the appendices for detailed material properties for the mirror materials in table 1. The text below gives some general information about the mirror materials.

- Beryllium. Beryllium “has flown on some of the most ambitious spacecraft programs undertaken, from the Apollo landers to deep space probes like Voyager” and has been used as an optical substrate on many missions, including Voyager, the Relay Mirror Experiment, and AOA.<sup>6</sup> Brush Wellman, the main supplier of beryllium, has the capability to produce near-net-shape beryllium optical substrates by hot isostatic pressing (HIP), cold isostatic pressing (CIP), and cold pressing of beryllium powders.<sup>7</sup> Please refer to appendices A and B for Beryllium I-70A and Beryllium O-50 material properties.
- Pure Nickel. Nickel was recommended for the NGST study by the Optics Lab (EB52) at NASA MSFC. Cold-worked nickel is one of the most ductile materials available. It has an advantage over some other optical materials under consideration, in that it can be machined and joined easily. However, it also has some disadvantages, including a high-mass density, low-specific stiffness, and thermal deformation parameters that are not favorable until the material becomes very cold. There are many factors to consider when choosing a material, and these may influence the selection of a baseline mirror material as the project’s life cycle proceeds.

Some forms of nickel that are available include, but are not limited to, Nickel 200 (commercially pure-wrought nickel), Nickel 201 (low-carbon grade), and Inco’s Duranickel™ alloy (containing 4.4% Al and 0.6% Ti). One may also hear about electroless nickel. Do not confuse this with pure nickel because it is a coating. “Electroless nickel plating is a controlled autocatalytic reduction of nickel ions by a suitable reducing agent, such as sodium hypophosphite, on a catalytic surface such as iron or aluminum. The resulting deposit is not a pure nickel, but essentially an alloy of nickel and phosphorus (if the normally used hydrophosphite salt is utilized as a reducing agent).”<sup>8</sup> Refer to appendix C for pure nickel material properties.

- Electrodeposited Nickel (EdNi). Beginning in October 1996, MSFC’s Optics Lab (EB52) was working on an NGST mirror replication task in which their charter was to “produce high-quality subscale prototype normal incidence mirror elements for the NGST”.<sup>9</sup> For the replication, they used an aluminum mandrel, deposited a layer of electroless nickel on it, a layer of gold, and then the final electrolytic nickel mirror surface. They produced the electrolytic nickel in-house using the Barrett process and sulfamate nickel.<sup>10</sup> However, since material properties for their nickel have not been determined yet through a material test program, some material property data for EdNi will be quoted as a representative sample.

EdNi “is a dense, essentially pure form of nickel. Because of the nature of the electrodeposition process, intricate contours can be readily and economically reproduced or covered with this form of nickel. EdNi can be deposited in thicknesses ranging from thin films to 1 inch or more. Mechanical properties of annealed EdNi are comparable to those of wrought Nickel 200. In the as-deposited form, the strength and hardness are higher than those of Nickel 200.”<sup>11</sup> Refer to appendix D for EdNi material properties.

- Chemical Vapor Deposition (CVD) Silicon Carbide™ (SiC). CVD SiC™ is a free-standing, monolithic single-phase cubic material with high purity, no porosity, superior chemical resistance, thermal conductivity, stiffness, and polishability. It is a result of Morton International’s bulk CVD process.<sup>12</sup> Other vendors and forms of SiC—like reaction bonded SiC, hot pressed SiC, and sintered SiC—are available. CVD SiC™ only represents one possible candidate out of many.

- Fabrication: “CVD SiC™ parts up to 60 inches (1.5 m) in diameter and 1 inch (25 mm) thick are available.”<sup>13</sup> Engineers in NASA MSFC’s cost group are currently checking on the cost of enlarging these facilities for NGST. Refer to appendix E for CVD SiC™ material properties.
- Silicon Dioxide Glass (Fused Silica & Fused Quartz). Fused silica is the common name for the polycrystalline form of silicon dioxide, a common glass material. Silicon dioxide is also known as quartz, but quartz should not be confused with fused silica because its structure is crystalline and its material properties (thermal conductivity at least) are orthotropic.<sup>14</sup> Refer to appendices F and G for fused silica and fused quartz material properties.
- ULE 7971. ULE™ is Corning Incorporated’s Code 7971 Ultra Low Expansion titanium silicate glass.<sup>15</sup> The Hubble Space Telescope’s 2.4-m diameter primary mirror blank was made from lightweighted ULE.
  - Fabrication: From a *single boule*, solid shapes up to 1.4 m in diameter by 15 cm thick can be fabricated. In addition, Corning’s *flowout process* can be used to produce sizes up to 2.8 m in diameter; and a *hex sealing* process can be used to manufacture sizes up to 10 m in diameter. Hex seal technology was used to produce the 8.3-m ULE mirror blank for the Subaru Telescope which will be located atop Mauna Kea, Hawaii. In 1995, Corning completed the first 8.1-m ULE mirror blank for the Gemini 8-M Telescopes Project which will construct twin telescopes on Mauna Kea and on Cerro Pachon, Chile.<sup>16</sup> Refer to appendix H for ULE 7971 material properties.
- Zerodur. Zerodur is a glass ceramics material that Schott Glass Technologies, Inc., has developed for optical, optoelectronic, and precision engineering applications.<sup>17</sup> It is an inorganic, nonporous material which has a crystalline phase and a glassy phase. Zerodur mirror substrates have been built for various telescopes, including NASA’s Advanced X-Ray Astrophysics Facility (AXAF) telescope, the ESO New Technology Telescope, and several telescopes for the Max-Planck-Institute for Astronomy in Heidelberg. Fabrication of parts up to 8.2 m in diameter is possible.<sup>18</sup> Refer to appendix I for Zerodur material properties.



### 3. MATERIAL SELECTION COMPARISON FACTORS

Many factors should be considered when trying to determine a suitable material for the mirror substrate of a space-based telescope. An effort was undertaken to identify many of the comparison factors, or figures of merit, which are pertinent to the selection of a telescope's mirror material. Table 2 lists these comparison factors, their definitions, and metric units. The table is loosely divided into seven categorical groupings of comparison factors: (1) structural figures of merit, (2) life cycle factors, (3) material homogeneity and stability, (4) thermal deformations, (5) optical scatter measurements, (6) reflectance, and (7) cost.

Table 2. Telescope mirror materials: some factors to consider.

Parameter	Definition	Units	Criteria
Specific Stiffness	E/rho	MJ/kg	High is Good
Specific Strength	YTS/rho	kJ/kg	High is Good
Microyield Strength (Temporal Stability Due to Creep)	Stress Producing 1% Creep in 100,000 Hours	MPa	High is Good
Fracture Toughness	K1c		
Anisotropy (Property homogeneity)	Ratio of Directional Mat'l Properties	Dimensionless	Near 1 is Good
Hysteresis Due to Thermal Cycling	Optical Figure Change	Waves r.m.s.	Low is Good
Steady State Thermal Distortion	CTE/k	cm/Megawatt	Near 0 is Good
Transient Thermal Distortion	(CTE-rho-Cp)/k	$\mu$ sec/cm <sup>2</sup> -K	Near 0 is Good
Surface Figure -Peak-to-Valley Deformation -Curvature Tilt	$\Delta$ (Deformed- Undeformed Shape	mm (Microns) Micro-Radians	Low is Good Near 0 is Good
Surface Microroughness	Departure of Surface From Plane	Angstroms r.m.s.	Low is Good
Optical Scatter	Scatter From Reflecting Surface	Angstroms r.m.s.	Low is Good
Reflectance (Normal Incidence)	$R = [(n - \lambda)^2 + \lambda k^2] / [(n + \lambda)^2 + \lambda k^2]$	percent (%)	High is Good
Cost	Price/Diameter	\$/cm	Low is Good

- Stress and Deformations. The structural figures of merit, specific stiffness and specific strength, are good indications of how different materials can be compared in terms of stress and deformation due to structural loads. Structural loads which must be considered are quasi-static, random vibration and acoustic loads (from launch), thermal, crew-induced loads (if any, on orbit), and shock from transportation and separation events.
- Thermal. Thermal loads and their impact on thermal deformations and figure changes have always been an important consideration for space-based telescopes. Thermal loads for mirrors can be characterized as bulk temperature excursions, axial (through the thickness) gradients, and diametrical (across-the-span) gradients.

### **3.1 Other Considerations**

Studies must consider many other factors as their telescope projects mature. Two of the most important questions concern material availability (their technology readiness level) and ease of fabrication to the telescope's desired size and precision. These factors have been difficult to quantify for the NGST study. As of June 1997, engineers in the NASA's cost group have been attempting to get quotes from private industry optical firms to estimate the cost of producing facilities large enough to handle the NGST optics.

Packaging considerations also lead to some very important questions, such as; will the design fit within a launch vehicle? Will there be any deployment mechanisms? There are also programmatic considerations such as budget, mass, and volumetric constraints; service life; and repair and maintenance.

#### 4. CONCLUSION

This NASA technical memorandum reports on the mirror material properties that were compiled from April 1996 to June 1997, for preliminary design of the NGST. Detailed material properties are included in the appendix.

The careful and systematic selection of a mirror material for a space-based telescope is a difficult task because of the many interactions that exist due to structural, thermal, optical, and configuration considerations during the telescope's design. Mirror material selection is very important because it will also affect the selection of materials for the telescope's reaction structure, mirror support, and metering structure. The combination of mirror material and metering structure materials is critical in determining the total system performance. A strain-free and thermally insensitive mirror has little benefit if the metering structure is sensitive to thermal loads. But if the mirrors and metering structure are the same material, or are otherwise athermalized, then temperature soaks can be compensated.

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## APPENDIX A

### **Beryllium I-70A Material Properties**

In October 1997, the authors intended for appendices A and B to contain material properties for Beryllium I-70 and Beryllium O-50. However, after a review of our sources for these properties, we realized that the major contributing source was export controlled.

After discussions with our management and export control officers, we decided in March 1998 to remove the table of beryllium material properties. Instead, we will list the sources of the properties for your reference.

#### **Beryllium sources that are NOT export controlled.**

##### Contained CTE vs. temperature data for Beryllium O-50

Swenson, "HIP beryllium: Thermal expansivity from 4 to 300 K and heat capacity from 1 to 108 K," Journal of Applied Physics, 70(6), Sept. 1991.

##### Contained Poisson's ratio and Elastic Modulus vs. temperature data for Beryllium I-70

J. Focht and D. Caldwell, "Beryllium Materials Characterization Report," Report No. K89-72U(R), Kaman Science Corp., Colorado Springs, CO, Aug. 4, 1989.

#### **The major source which DOES contain Export Controlled Information.**

D.H. Killpatrick, "Report on the Properties of Beryllium," prepared by RDA Logicon for MODIL, Oak Ridge National Laboratory, Purchase Order 90X-SE860V, May 1990.

*"WARNING—This document contains technical data whose export (including transmission to non-resident aliens) is restricted by the Arms Export Controls Act (22 USC 2751 et seq) or the Export Administration Act of 1979, as amended (50 USC 2401 et seq).*

*Violations of these export laws are subject to criminal penalties."*

#### **A Supplier of Beryllium.**

Brush Wellman, Beryllium/Mining Division, 14710 W. Portage River S. Rd., Elmore, Ohio 43416, (419) 862-4205. <http://www.brushwellman.com/www/homepage.html>





## **APPENDIX B**

### **Beryllium O-50 Material Properties**

In October 1997, the authors intended for appendices A and B to contain material properties for Beryllium I-70 and Beryllium O-50. However, after a review of our sources for these properties, we realized that the major contributing source was export controlled.

After discussions with our management and export control officers, we decided in March 1998 to remove the table of beryllium material properties. Instead, we will list the sources of the properties for your reference.

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##### Contained CTE vs. temperature data for Beryllium O-50

Swenson, "HIP beryllium: Thermal expansivity from 4 to 300 K and heat capacity from 1 to 108K," Journal of Applied Physics, 70(6), Sept. 1991.

##### Contained Poisson's ratio and Elastic Modulus vs. temperature data for Beryllium I-70

J. Focht and D. Caldwell, "Beryllium Materials Characterization Report," Report No. K89-72U(R), Kaman Science Corp., Colorado Springs, CO, Aug. 4, 1989.

#### **The major source which DOES contain Export Controlled Information.**

D.H. Killpatrick, "Report on the Properties of Beryllium," prepared by RDA Logicon for MODIL, Oak Ridge National Laboratory, Purchase Order 90X-SE860V, May 1990.

*"WARNING—This document contains technical data whose export (including transmission to non-resident aliens) is restricted by the Arms Export Controls Act (22 USC 2751 et seq) or the Export Administration Act of 1979, as amended (50 USC 2401 et seq).*

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## APPENDIX C

### Pure Nickel Material Properties

This appendix contains material properties for pure nickel.

Properties. Listed in the following charts are mass density, thermal properties (specific heat, thermal conductivity), and mechanical properties (CTE, modulus of elasticity, Poisson's ratio, and material strength). When available, properties are given over the temperature range of interest for the NGST, from 30 to 294 K.

Average CTE values. To assist structural analysts, we calculated average CTE values for the different materials, where possible, for a temperature drop from room temperature down to the NGST's operating temperature range. We numerically integrated the CTE curve to get thermal strain and then divided by the change in temperature to get an average CTE from 294 to 30 K. If available, these average CTE values are shown below the CTE plots for the various mirror materials.

Caution. The listed material strengths are often denoted as being average, typical values. When a telescope project matures, we advise that A-Basis properties be used instead. A-Basis values represent the value at which at least 99 percent of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95 percent.<sup>19</sup>

Special notations by the data. If a text notation appears next to a value, *calc.* indicates that the value was calculated from other data in the table, *int.* means that the value was linearly interpolated, and *assume* indicates that the density was assumed to be relatively constant versus temperature. All other values represent data that was measured in a laboratory.

# MATERIAL PROPERTIES: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:** Pure Nickel

**SUPPLIER:** Thomas Register of American Manufacturers listed 33 "Nickel: Pure" suppliers, downloaded 11-15-96 from WWW at <http://www.thomasregister.com:8000/index.html>

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

## MATERIAL PROPERTIES: 15-Nov-96

Direction =												
Basis =		Typical	Typical	Typical	Typical		Typical	Typical				
Type =												
Temperature		Density	Ultimate Strength	Yield Strength	Elastic Modulus	Poisson's Ratio	Microyield Strength	CTE	Thermal Conductivity	Specific Heat	Radiative Absorptivity	Radiative Emmissivity
( C)	( °K)	rho (kg/m^3)	UTS (MPa)	YTS (MPa)	E (GPa)	mu (—)		(per °K)	k (W/m-K)	Cp (J/kg-K)	alpha	epsilon
-253 C	20 °K				214.2					5.2		
-249 C	24 °K	Assumed 8913						8.64E-6	860	10.5		
-240 C	33 °K	Assumed 8913			214.2			8.79E-6	657.6	16.7		
-224 C	49 °K				214.2			int. 9.17E-6		62.8		
-212 C	61 °K	Assumed 8913						9.46E-6	257.2	105		
-184 C	89 °K	Assumed 8913						1.01E-5	173.1	209		
-173 C	100 °K	Assumed 8913						int. 1.03E-5	164	230		
-156 C	117 °K							1.05E-5	138.5			
-143 C	130 °K							1.08E-5				
-129 C	144 °K	Assumed 8913			206.8			1.10E-5	123.6	335		
-73 C	200 °K	Assumed 8913						1.12E-5	108.9	387		
-45 C	228 °K							1.15E-5	103.8			
-33 C	240 °K				197			int. 1.19E-5		418		
21 °C	294 °K	8913	689.5	344.7	197	0.287L, 0.281T		1.35E-5	88.96	460		
1455 C	1728 °K											

**FABRICATION:** Maximum = parts up to TBD diameter and TBD thick.  
Minimum = somewhere in the ballpark of TBD.

**REFERENCES:**

- CTE (except 294K), k (except 100K), E.
- rho, CTE at 294K, YTS, UTS.
- k at 100K.
- Cp
- Poisson's ratio

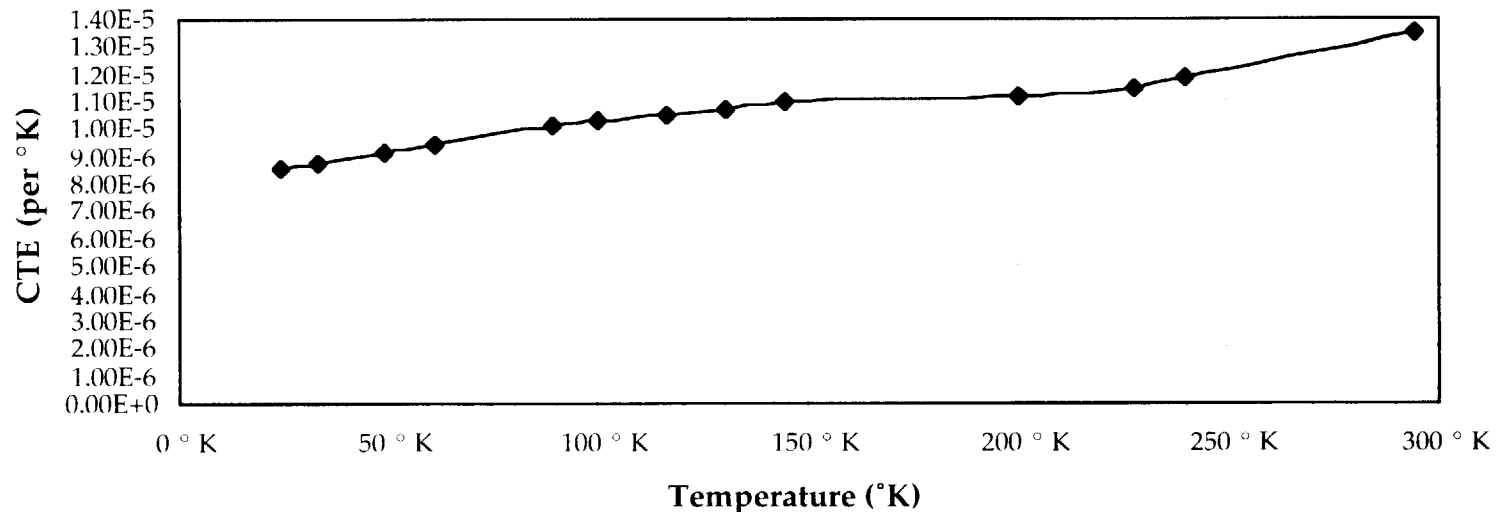
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## CTE of PURE NICKEL

The CTE is a calculated value, derived by taking the derivative of the measured thermal strain plot with respect to temperature.

Pure Nickel CTE vs. Temperature



Likewise, the test specimen's thermal strain from point T1 to point T2 can be calculated by integrating the CTE curve. This strain can then be divided by the change in temperature (T1-T2) to get an *average* CTE that can be used by analysts to simplify their thermal strain calculations for other structural configurations.

For a bulk temperature drop from 294 °K to 60 °K, the *average* CTE=11.23 E-6 per °K; and from 294 °K to 30 °K, the *average* CTE=11.01 E-6 per °K.

# Material FIGURES OF MERIT: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:** Pure Nickel

**SUPPLIER:** Thomas Register of American Manufacturers listed 33 "Nickel: Pure" suppliers, downloaded 11-15-96 from WWW at <http://www.thomasregister.com:8000/index.html>

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

## FIGURES OF MERIT: 15-Nov-96

Direction =						
Basis =		Typical	Typical	Typical	Thermal	Thermal
Type =		Strength	Strength	Deflection	Deform.	Deform.
Temperature		Driven	Driven	Driven	Steady-state	Transient
		<b>Specific</b>	<b>Specific</b>	<b>Specific</b>	<b>Distortion</b>	<b>Distortion</b>
		<b>Strength</b>	<b>Strength</b>	<b>Stiffness</b>		
(°C)	(°K)	UTS / rho	YTS / rho	E / rho	CTE / k	CTE-rho-Cp / k
		(kJ/kg)	(kJ/kg)	(MJ/kg)	(cm/MW)	E-6(sec/cm^2-K)
-253 °C	20 °K					
-249 °C	24 °K				1.00	0.09
-240 °C	33 °K			24.0	1.34	0.20
-224 °C	49 °K					
-212 °C	61 °K				3.68	3.44
-184 °C	89 °K				5.83	10.87
-173 °C	100 °K				6.25	12.82
-156 °C	117 °K				7.58	
-143 °C	130 °K					
-129 °C	144 °K			23.2	8.90	26.57
-73 °C	200 °K				10.28	35.48
-45 °C	228 °K				11.08	
-33 °C	240 °K					
21 °C	294 °K	77.4	38.7	22.1	15.18	62.22
1455 °C	1728 °K					
		^	^	^	^	^
		high	high	high	near zero	near zero
		is good	is good	is good	is good	is good

## APPENDIX D

### Electrodeposited Nickel Material Properties

This appendix contains material properties for electrodeposited nickel.

Properties. Listed in the following charts are mass density, thermal properties (specific heat, thermal conductivity), and mechanical properties (CTE, modulus of elasticity, Poisson's ratio, and material strength). When available, properties are given over the temperature range of interest for the NGST, from 30 to 294 K.

Average CTE values. To assist structural analysts, we calculated average CTE values for the different materials, where possible, for a temperature drop from room temperature down to the NGST's operating temperature range. We numerically integrated the CTE curve to get thermal strain and then divided by the change in temperature to get an average CTE from 294 to 30 K. If available, these average CTE values are shown below the CTE plots for the various mirror materials.

Caution. The listed material strengths are often denoted as being average, typical values. When a telescope project matures, we advise that A-Basis properties be used instead. A-Basis values represent the value at which at least 99 percent of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95 percent.<sup>19</sup>

Special notations by the data. If a text notation appears next to a value, *calc.* indicates that the value was calculated from other data in the table, *int.* means that the value was linearly interpolated, and *assume* indicates that the density was assumed to be relatively constant versus temperature. All other values represent data that was measured in a laboratory.

# MATERIAL PROPERTIES: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:** Electrodeposited Nickel (EdNi)

**SUPPLIER:** N/A

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

## MATERIAL PROPERTIES: 22-Nov-96

Direction =															
Basis =		Typical	Exp. Min.	Exp. Min.	Typical	Typical		Typical	Typical	Typical	Typical	Exp. Min.	Exp. Min.	Typical	Typical
Type =			As-Deposited	As-Deposited	Elastic	Poisson's	Microyield					Compressive	Compressive		
Temperature		Density	Ultimate	Yield	Modulus	Ratio	Strength	CTE	Thermal	Specific	Radiative	Radiative	Strength	Strength	Strength
( C )	( °K )	rho	Strength	Strength	E	mu		(per K)	Conductivity	Heat	Absorptivity	Emissivity			
		(kg/m^3)	UTS	YTS	(GPa)	(—)			k	Cp	alpha	epsilon	(MPa)	(MPa)	(MPa)
			(MPa)	(MPa)					(W/m-K)	(J/kg-K)					
-243 C	30 °K								605	30					
-228 C	45 °K								380	40					
-213 C	60 °K								295	55					
-195 C	78 °K		855	483					200	75				459	
-173 C	100 °K		814	476					170	90				452	
-151 C	122 °K		772	469					145	105				448	
-129 C	144 °K		738	455					130	120				441	
-107 C	166 °K		717	448					120	130				434	
-84 C	189 °K		690	441					110	140				428	
-62 C	211 °K		669	434					100	150				421	
-40 C	233 °K		655	428					90	160				417	
-18 C	255 K		641	421					85	170				410	
5 C	278 °K		634	414					85	175				403	
22 °C	295 °K	8854	614	414	180	0.264		1.47E-5	83.04	180				400	
1435 °C	1708 K														

**FABRICATION:** Maximum = parts up to 1BD diameter and 1BD thick.  
Minimum = somewhere in the ballpark of 1BD.

**REFERENCES:**

- At NASA/MSFC, EB52 produces electrolytic nickel with the Barrett process from sulfate nickel (11-22-96).
- Anon., "Material Properties Manual", Rockwell International: Rocketdyne Div., Materials Engineering & Tech., Vol IIA, 4th Ed., 1-31-87.

# Material FIGURES OF MERIT: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:**      **Electrodeposited Nickel (EdNi)**

**SUPPLIER:**              N/A

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

## FIGURES OF MERIT:              22-Nov-96

Direction =						
Basis =		Exp. Min.	Exp. Min.	Typical.		
Type =		Strength	Strength	Deflection	Thermal	Thermal
Temperature		Driven	Driven	Driven	Deform.	Deform.
		<b>Specific</b>	<b>Specific</b>	<b>Specific</b>	<b>Steady-state</b>	<b>Transient</b>
		<b>Strength</b>	<b>Strength</b>	<b>Stiffness</b>	<b>Distortion</b>	<b>Distortion</b>
(°C)	(°K)	UTS/rho	YTS/rho	E/rho	CTE/k	CTE-rho-Cp/k
		(kJ/kg)	(kJ/kg)	(MJ/kg)	(cm/MW)	E-6(sec/cm <sup>2</sup> -K)
-243 °C	30 K					
-228 °C	45 K					
-213 °C	60 K					
-195 °C	78 K					
-173 °C	100 K					
-151 °C	122 K					
-129 °C	144 K					
-107 °C	166 K					
-84 °C	189 K					
-62 °C	211 K					
-40 °C	233 K					
-18 °C	255 K					
5 °C	278 K					
22 °C	295 K	69.3	46.8	20.3	17.70	28.21
1435 °C	1708 K					
		^	^	^	^	^
		high	high	high	near zero	near zero
		is good	is good	is good	is good	is good



## APPENDIX E

### CVD Silicon Carbide™ Material Properties

This appendix contains material properties for CVD Silicon Carbide™.

Properties. Listed in the following charts are mass density, thermal properties (specific heat, thermal conductivity), and mechanical properties (CTE, modulus of elasticity, Poisson's ratio, and material strength). When available, properties are given over the temperature range of interest for the NGST, from 30 to 294 K.

Average CTE values. To assist structural analysts, we calculated average CTE values for the different materials, where possible, for a temperature drop from room temperature down to the NGST's operating temperature range. We numerically integrated the CTE curve to get thermal strain and then divided by the change in temperature to get an average CTE from 294 to 30 K. If available, these average CTE values are shown below the CTE plots for the various mirror materials.

Caution. The listed material strengths are often denoted as being average, typical values. When a telescope project matures, we advise that A-Basis properties be used instead. A-Basis values represent the value at which at least 99 percent of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95 percent.<sup>19</sup>

Special notations by the data. If a text notation appears next to a value, *calc.* indicates that the value was calculated from other data in the table, *int.* means that the value was linearly interpolated, and *assume* indicates that the density was assumed to be relatively constant versus temperature. All other values represent data that was measured in a laboratory.

# MATERIAL PROPERTIES: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

## Material: CVD Silicon Carbide™

SUPPLIER: Morton Advanced Materials  
185 New Boston Street  
Woburn, MA 01801-6203

tel: (617) 933-9243  
contact = Lee Burns at (617) 937-9102  
fax: (617) 933-5142

Morton International WWW = <http://www.mortoncvd.com/>

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

### MATERIAL PROPERTIES:

1-Jul-97

Direction =										
Basis =		Typical	Typical	Typical	Typical	Typical	Typical	Typical		
Type =			4-point flexural	4-point						
Temperature		<u>Density</u>	<u>Ultimate</u>	<u>Yield</u>	<u>Elastic</u>	<u>Poisson's</u>	<u>Microyield</u>	<u>CTE</u>	<u>Thermal</u>	<u>Specific</u>
(°C)	(°K)	rho	Strength	Strength	Modulus	Ratio	Strength		Conductivity	Heat
		(kg/m <sup>3</sup> )	UTS	YTS	E	mu		(per °K)	k	Cp
			(MPa)	(MPa)	(GPa)	(—)			(W/m-K)	(J/kg-K)
-273 °C	0 °K									
-150 °C	123 °K	calc. 3202		460				4.00E-7	360	146
-140 °C	133 °K	int. 3206							396	175
-100 °C	173 °K	calc. 3223		465				8.00E-7	485	301
0 °C	273 °K	calc. 3223		470	460			1.90E-6	333	574
<b>21 °C</b>	<b>294 °K</b>	<b>3210</b>		<b>470</b>	<b>461</b>	<b>0.21</b>		<b>2.20E-6</b>	<b>300</b>	<b>640</b>
100 °C	373 °K	calc. 3329						2.90E-6	272	817
200 °C	473 °K	calc. 3180		480	457			3.70E-6	221	952
300 °C	573 °K	calc. 3226						4.10E-6	192	1044
400 °C	673 °K	calc. 3192						4.40E-6	157	1093
500 °C	773 °K			500	450			4.60E-6	137	1134
700 °C	973 °K			515	440			4.90E-6	110	1189
1000 °C	1273 °K	calc. 3282		540	435			5.00E-6	78	1251
1200 °C	1473 °K	calc. 3243		555	422			5.10E-6	63	1295
1500 °C	1773 °K			575	415				48	1355

### FABRICATION:

Maximum = parts up to 60" (1.5m) diameter and 1" (25mm) thick.

Minimum = somewhere in the ballpark of 1-2 mm (dependent on diameter of substrate, curvature, surface finish, etc.).

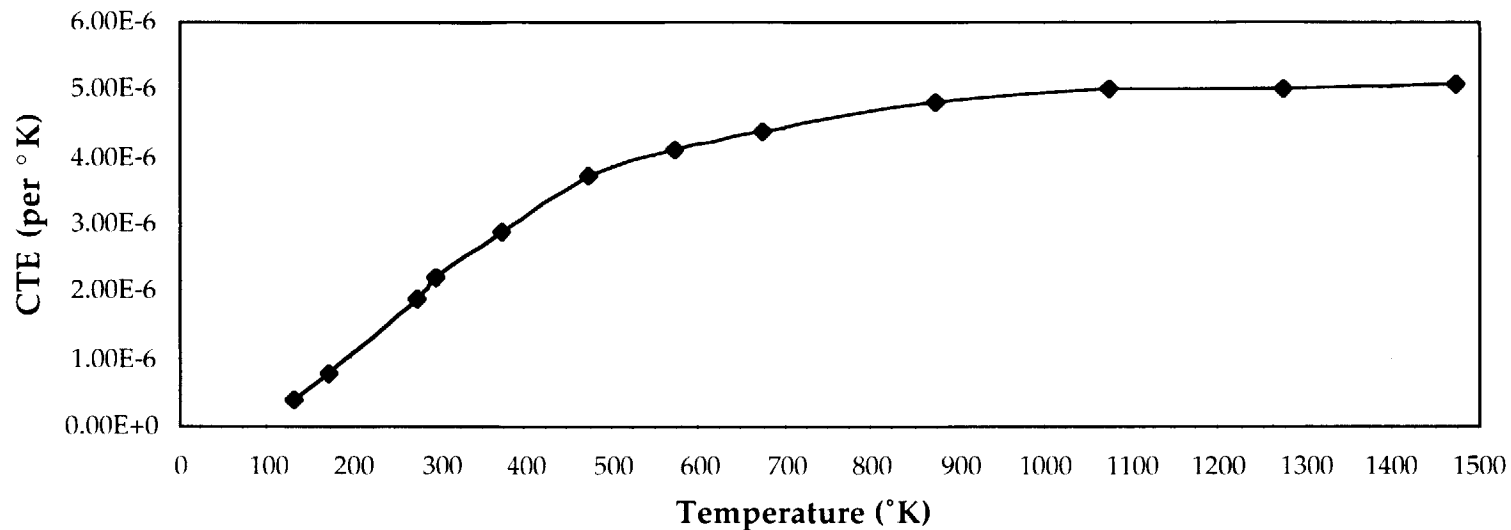
### REFERENCES:

- (1) Anon., "CVD Silicon Carbide™", Material specification SC-001, Morton Advanced Materials, Woburn, MA, October 1996.
- (2) Anon., "CVD Silicon Carbide™", CVD Materials Technical Bulletin #996, Revision 1, Morton Advanced Materials, Woburn, MA, September 1996.
- (3) <http://www.nashville.net/~ceramics/morton/cvdsic.html>, August 8, 1996. Verified existing properties and was able to add more properties at different temperatures.
- (4) Cp, k, CTE, E, Strength from measurements at Morton Advanced Materials, University of Dayton Research Institute, Thermophysical Properties Research Laboratory at Purdue University, and a number of other commercial and university laboratories (see ref 2, page 2).

## CTE of CVD™ SILICON CARBIDE

The CTE is a calculated value, derived by taking the derivative of the measured thermal strain plot with respect to temperature.

CVD Silicon Carbide™ CTE vs. Temperature



Likewise, the test specimen's thermal strain from point T1 to point T2 can be calculated by integrating the CTE curve. This strain can then be divided by the change in temperature (T1-T2) to get an *average* CTE that can be used by analysts to simplify their thermal strain calculations for other structural configurations.

The *average* CTE for CVD Silicon Carbide™ during the NGST temperature drop from 294 °K to 30 °K could *not* be calculated because we have data from a CTE curve that only goes down to 133 °K.

# Material **FIGURES OF MERIT** : Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:** **CVD Silicon Carbide™**

**SUPPLIER:** Morton Advanced Materials  
185 New Boston Street  
Woburn, MA 01801-6203

tel: (617) 933-9243  
contact = Lee Burns at (617) 937-9102  
fax: (617) 933-5142

Morton International WWW = <http://www.mortoncvd.com/>

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

## **FIGURES OF MERIT:** 1-Jul-97

Direction =						
Basis =						
Type =		Strength	Typical Strength	Typical. Deflection	Thermal Deform.	Thermal Deform.
Temperature		Driven	Driven	Driven	Steady-state	Transient
		<u>Specific</u>	<u>Specific</u>	<u>Specific</u>	<u>Distortion</u>	<u>Distortion</u>
		<u>Strength</u>	<u>Strength</u>	<u>Stiffness</u>		
(°C)	(°K)	UTS/rho	YTS/rho	E/rho	CTE/k	CTE-rho-Cp/k
(°C)	(°K)	(kJ/kg)	(kJ/kg)	(MJ/kg)	(cm/MW)	E-6(sec/cm².K)
-273 °C	0 °K					
-150 °C	123 °K					
-140 °C	133 °K		143.5		0.10	0.06
-100 °C	173 °K		144.3		0.16	0.16
0 °C	273 °K		145.8	142.7	0.57	1.06
21 °C	294 °K		146.4	143.6	0.73	1.51
100 °C	373 °K				1.07	2.90
200 °C	473 °K		150.9	143.7	1.67	5.07
300 °C	573 °K				2.14	7.19
400 °C	673 °K				2.80	9.78
500 °C	773 °K				3.36	
700 °C	973 °K				4.45	
1000 °C	1273 °K		164.6	132.6	6.41	26.32
1200 °C	1473 °K		171.1	130.1	8.10	34.00
1500 °C	1773 °K					
		^	^	^	^	^
		high	high	high	near zero	near zero
		is good	is good	is good	is good	is good

## APPENDIX F

### Fused Silica Glass Material Properties

This appendix contains material properties for fused silica glass.

Properties. Listed in the following charts are mass density, thermal properties (specific heat, thermal conductivity), and mechanical properties (CTE, modulus of elasticity, Poisson's ratio, and material strength). When available, properties are given over the temperature range of interest for the NGST, from 30 to 294 K.

Average CTE values. To assist structural analysts, we calculated average CTE values for the different materials, where possible, for a temperature drop from room temperature down to the NGST's operating temperature range. We numerically integrated the CTE curve to get thermal strain and then divided by the change in temperature to get an average CTE from 294 to 30 K. If available, these average CTE values are shown below the CTE plots for the various mirror materials.

Caution. The listed material strengths are often denoted as being average, typical values. When a telescope project matures, we advise that A-Basis properties be used instead. A-Basis values represent the value at which at least 99 percent of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95 percent.<sup>19</sup>

Special notations by the data. If a text notation appears next to a value, *calc.* indicates that the value was calculated from other data in the table, *int.* means that the value was linearly interpolated, and *assume* indicates that the density was assumed to be relatively constant versus temperature. All other values represent data that was measured in a laboratory.

# MATERIAL PROPERTIES: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:** Fused Silica—Silicon Dioxide, Polycrystalline.

**SUPPLIER:** N/A

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

## MATERIAL PROPERTIES: 1-Jun-92

Direction =												
Basis =		Typical	Typical		Typical		Typical	Typical	Typical			
Type =												
Temperature		<u>Density</u> rho (kg/m^3)	<u>Ultimate Strength</u> UTS (MPa)	<u>Yield Strength</u> YTS (MPa)	<u>Elastic Modulus</u> E (GPa)	<u>Poisson's Ratio</u> mu (—)	<u>Microyield Strength</u>	<u>CTE</u> (per °K)	<u>Thermal Conductivity</u> k (W/m-K)	<u>Specific Heat</u> Cp (J/kg-K)	<u>Radiative Absorptivity</u> alpha	<u>Radiative Emmissivity</u> epsilon
(°C)	(°K)											
-273 °C	0 °K	2200			72	0.244		5.50E-7				
-223 °C	50 °K											
-173 °C	100 °K											
-123 °C	150 °K										0.69	
-73 °C	200 °K											418.655
-23 °C	250 °K										1.14	544.252
0 °C	273 °K											661.475
21 °C	294 °K											
27 °C	300 °K							1.38	745			

**FABRICATION:** Maximum = parts up to TBD diameter and TBD thick.  
Minimum = somewhere in the ballpark of TBD.

**REFERENCES:**

- rho, CTE, Cp, E, Poisson's ratio, Y.S. Tououkian, "Thermophysical Properties of High Temperature Solids".
- k Incropera and DeWitt, Fundamentals of heat and Mass Transfer, Third Edition, 1990, Appendix A, p A8.
- Doubled-checked 294K props. Dibble, M.A. (ed.), "material Selection", Machine Design: 1992 Basics of Design Engineering Reference Volume, Vol. 64, No. 12, June 1992, p 969.

# Material FIGURES OF MERIT: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:** Fused Silica—Silicon Dioxide, Polycrystalline.

**SUPPLIER:** N/A/

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

## FIGURES OF MERIT: 1-Jun-92

Direction =						
Basis =		<i>Typical</i>				
Type =		Strength	Strength	Deflection	Thermal	Thermal
		Driven	Driven	Driven	Deform.	Deform.
Temperature		<b>Specific</b>	<b>Specific</b>	<b>Specific</b>	<b>Steady-State</b>	<b>Transient</b>
		<b>Strength</b>	<b>Strength</b>	<b>Stiffness</b>	<b>Distortion</b>	<b>Distortion</b>
(°C)	(°K)	UTS/rho	YTS/rho	E/rho	CTE/k	CTE-rho-Cp/k
		(kJ/kg)	(kJ/kg)	(MJ/kg)	(cm/MW)	E-6(sec/cm^2-K)
-273 °C	0 °K					
-223 °C	50 °K					
-173 °C	100 °K					
-123 °C	150 °K					
-73 °C	200 °K					
-23 °C	250 °K					
0 °C	273 °K					
21 °C	294 °K			32.7	39.86	65.32
27 °C	300 °K					
	0 °K					
	0 °K					
	0 °K					
	0 °K					
	0 °K					
	0 °K					
	0 °K					
		^	^	^	^	^
		high	high	high	near zero	near zero
		is good	is good	is good	is good	is good

## APPENDIX G

### Fused Quartz Glass Material Properties

This appendix contains material properties for fused quartz glass.

Properties. Listed in the following charts are mass density, thermal properties (specific heat, thermal conductivity), and mechanical properties (CTE, modulus of elasticity, Poisson's ratio, and material strength). When available, properties are given over the temperature range of interest for the NGST, from 30 to 294 K.

Average CTE values. To assist structural analysts, we calculated average CTE values for the different materials, where possible, for a temperature drop from room temperature down to the NGST's operating temperature range. We numerically integrated the CTE curve to get thermal strain and then divided by the change in temperature to get an average CTE from 294 to 30 K. If available, these average CTE values are shown below the CTE plots for the various mirror materials.

Caution. The listed material strengths are often denoted as being average, typical values. When a telescope project matures, we advise that A-Basis properties be used instead. A-Basis values represent the value at which at least 99 percent of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95 percent.<sup>19</sup>

Special notations by the data. If a text notation appears next to a value, *calc.* indicates that the value was calculated from other data in the table, *int.* means that the value was linearly interpolated, and *assume* indicates that the density was assumed to be relatively constant versus temperature. All other values represent data that was measured in a laboratory.



# MATERIAL PROPERTIES: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:** Fused Quartz, GE Type 214 — Silicon Dioxide, Crystalline Silica (From Sand or Rock).

**SUPPLIER:**

General Electric  
GE Willoughby Quartz Plant  
Willoughby, OH

tel = ?  
fax = ?  
e-mail = quartz@lighting.ge.com

General Electric Quartz WWW = <http://www.ge.com/quartz/catalog.htm>  
Fused Quartz WWW = <http://www.users.fast.net/~wa3key/gedata.html>

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

**MATERIAL PROPERTIES:**

7-May-97

MATERIAL PROPERTIES.													
Direction =			Typical					Typical	Typical				Typical
Basis =		Typical	Design Tensile										Design
Type =			Ultimate	Yield	Elastic	Poisson's	Microyield		Thermal	Specific	Radiative	Radiative	Compressive
Temperature		Density	Strength	Strength	Modulus	Ratio	Strength	CTE	Conductivity	Heat	Absorptivity	Emmissivity	Strength
( °C )	( °K )	rho	UTS	YTS	E	mu		(per °K)	k	Cp	alpha	epsilon	MPa
		(kg/m^3)	(MPa)	(MPa)	(GPa)	(—)			(W/m-K)	(J/kg-K)			
-273 °C	0 °K	2200	48.3	72.4	0.17			5.50E-7	1.4	670			1100
-150 °C	123 °K												
-140 °C	133 °K												
-100 °C	173 °K												
0 °C	273 °K												
21 °C	294 °K												
100 °C	373 °K												
200 °C	473 °K												
300 °C	573 °K												
400 °C	673 °K												
600 °C	873 °K												
800 °C	1073 °K												
1000 °C	1273 °K												
1200 °C	1473 °K												
1500 °C	1773 °K												

**FABRICATION:**

Maximum = parts up to TBD diameter and TBD thick.  
Minimum = somewhere in the ballpark of TBD

**REFERENCES:**

- 294K props <http://www.users.fast.net/~wa3key/gedata.html> (Downloaded 5-7-97. Web page revision = August 6, 1996).

# Material FIGURES OF MERIT: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

## Material: Fused Quartz, GE Type 214—Silicon Dioxide, Crystalline Silica (From Sand or Rock).

**SUPPLIER:**

General Electric  
GE Willoughby Quartz Plant  
Willoughby, OH

tel = ?  
toll-free sales = (800) 438-2100  
fax = ?  
e-mail = quartz@lighting.ge.com

General Electric Quartz WWW = <http://www.ge.com/quartz/catalog.htm>  
Fused Quartz WWW = <http://www.users.fast.net/~wa3key/geedata.html>

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

### FIGURES OF MERIT: 7-May-97

Direction =						
Basis =		Typical				
Type =		Strength	Strength	Deflection	Thermal	Thermal
Temperature		Driven	Driven	Driven	Deform.	Deform.
		<b>Specific</b>	<b>Specific</b>	<b>Specific</b>	<b>Steady-state</b>	<b>Transient</b>
		<b>Strength</b>	<b>Strength</b>	<b>Stiffness</b>	<b>Distortion</b>	<b>Distortion</b>
(°C)	(°K)	UTS/rho	YTS/rho	E/rho	CTE/k	CTE-rho-Cp/k
		(kJ/kg)	(kJ/kg)	(MJ/kg)	(cm/MW)	E-6(sec/cm^2-K)
-273 °C	0 °K	22.0	32.9	39.29	57.91	
-150 °C	123 °K					
-140 °C	133 °K					
-100 °C	173 °K					
0 °C	273 °K					
21 °C	294 °K					
100 °C	373 °K					
200 °C	473 °K					
300 °C	573 °K					
400 °C	673 °K					
600 °C	873 °K					
800 °C	1073 °K					
1000 °C	1273 °K					
1200 °C	1473 °K					
1500 °C	1773 °K					
		high is good	high is good	high is good	near zero is good	near zero is good

## APPENDIX H

### ULE 7971 Material Properties

This appendix contains material properties for ULE 7971.

Properties. Listed in the following charts are mass density, thermal properties (specific heat, thermal conductivity), and mechanical properties (CTE, modulus of elasticity, Poisson's ratio, and material strength). When available, properties are given over the temperature range of interest for the NGST, from 30 to 294 K.

Average CTE values. To assist structural analysts, we calculated average CTE values for the different materials, where possible, for a temperature drop from room temperature down to the NGST's operating temperature range. We numerically integrated the CTE curve to get thermal strain and then divided by the change in temperature to get an average CTE from 294 to 30 K. If available, these average CTE values are shown below the CTE plots for the various mirror materials.

Caution. The listed material strengths are often denoted as being average, typical values. When a telescope project matures, we advise that A-Basis properties be used instead. A-Basis values represent the value at which at least 99 percent of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95 percent.<sup>19</sup>

Special notations by the data. If a text notation appears next to a value, *calc.* indicates that the value was calculated from other data in the table, *int.* means that the value was linearly interpolated, and *assume* indicates that the density was assumed to be relatively constant versus temperature. All other values represent data that was measured in a laboratory.

# MATERIAL PROPERTIES: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

## Material: ULE™—Corning's Code 7971 Ultra Low Expansion Titanium Silicate Glass

**SUPPLIER:** Corning Incorporated  
Advanced Materials Business  
HP CP-08  
Corning, NY 14831

Sales = (607) 974-7440.  
Customer service = (607) 974-7597.  
Fax = (607) 974-7210.

WWW = <http://www.corning.com/>

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

### MATERIAL PROPERTIES: 5-Jul-96

Direction =											
Basis =	Typical	Typical	Typical	Typical		Typical	Typical	Typical			
Type =											
Temperature	<b>Density</b> rho (kg/m <sup>3</sup> )	<b>Ultimate Strength</b> UTS (MPa)	<b>Yield Strength</b> YTS (MPa)	<b>Elastic Modulus</b> E (GPa)	<b>Poisson's Ratio</b> mu (—)	<b>Microyield Strength</b>	<b>CTE</b> (per °K)	<b>Thermal Conductivity</b> k (W/m-K)	<b>Specific Heat</b> Cp (J/kg-K)	<b>Radiative Absorptivity</b> alpha	<b>Radiative Emmissivity</b> epsilon
-243 °C 30 °K											
-228 °C 45 °K											
-213 °C 60 °K											
-200 °C 73 °K											
-173 °C 100 °K					64	0.158					
-150 °C 123 °K											
-100 °C 173 °K											
-75 °C 198 °K							-2.70E-7				
-60 °C 213 °K											
-50 °C 223 °K					66		-1.80E-7	1.3			
-25 °C 248 °K							-1.00E-7				
0 °C 273 °K							-3.00E-8				
21 °C 294 °K											
25 °C 298 °K	2210	49.8		67.6	0.17		2.00E-8	1.31	767		
1000 °C 1273 °K											

**FABRICATION:** Maximum = monolithic solids up to 10 m diameter and TBD thick.  
Minimum = somewhere in the ballpark of a few centimeters diameter and TBD thick.

**REFERENCES:** • Anonymous, "Zero Expansion Glass ULE™", Corning Incorporated, Corning, NY 14831, dated March 1996.

# Material FIGURES OF MERIT: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

**Material:** ULE™ - Corning's Code 7971 Ultra Low Expansion Titanium Silicate Glass.

**SUPPLIER:** Corning Incorporated  
Advanced Materials Business  
HP-CP-08  
Corning, NY 14831

Sales = (607) 974-7440.  
Customer service = (607) 974-7597.  
Fax = (607) 974-7210.

WWW = <http://www.corning.com/>

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

## FIGURES OF MERIT: 5-Jul-96

Direction =						
Basis =		Typical	Typical			
Type =		Strength	Deflection	Thermal	Thermal	
		Driven	Driven	Deform.	Deform.	
Temperature		<b>Specific</b>	<b>Specific</b>	<b>Steady-state</b>	<b>Transient</b>	
		<b>Strength</b>	<b>Stiffness</b>	<b>Distortion</b>	<b>Distortion</b>	
(°C)	(°K)	UTS/rho	E/rho	CTE/k	CTE-rho-Cp/k	
		(kJ/kg)	(MJ / kg)	(cm/MW)	E-6(sec/cm^2-K)	
-243 °C	30 °K					
-228 °C	45 °K					
-213 °C	60 °K					
-200 °C	73 °K					
-173 °C	100 °K					
-150 °C	123 °K					
-100 °C	173 °K					
-75 °C	198 °K					
-60 °C	213 °K					
-50 °C	223 °K			-13.85		
-25 °C	248 °K					
0 °C	273 °K					
21 °C	294 °K					
25 °C	298 °K	22.5	30.6	1.53	2.59	
1000 °C	1273 °K					
		high	high	near zero	near zero	
		is good	is good	is good	is good	

## APPENDIX I

### Zerodur Material Properties

This appendix contains material properties for Zerodur.

Properties. Listed in the following charts are mass density, thermal properties (specific heat, thermal conductivity), and mechanical properties (CTE, modulus of elasticity, Poisson's ratio, and material strength). When available, properties are given over the temperature range of interest for the NGST, from 30 to 294 K.

Average CTE values. To assist structural analysts, we calculated average CTE values for the different materials, where possible, for a temperature drop from room temperature down to the NGST's operating temperature range. We numerically integrated the CTE curve to get thermal strain and then divided by the change in temperature to get an average CTE from 294 to 30 K. If available, these average CTE values are shown below the CTE plots for the various mirror materials.

Caution. The listed material strengths are often denoted as being average, typical values. When a telescope project matures, we advise that A-Basis properties be used instead. A-Basis values represent the value at which at least 99 percent of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95 percent.<sup>19</sup>

Special notations by the data. If a text notation appears next to a value, *calc.* indicates that the value was calculated from other data in the table, *int.* means that the value was linearly interpolated, and *assume* indicates that the density was assumed to be relatively constant versus temperature. All other values represent data that was measured in a laboratory.

# MATERIAL PROPERTIES: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

## Material: Glass Ceramics Zerodur

**SUPPLIER:** Schott Glass Technologies, Inc.  
400 York Avenue  
Duryea, PA 18642

Contact = Bob Chamberlain  
(717) 457-7485 Ext. 305  
(717) 457-6960

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

**S-Basis** properties = the minimum value specified by the governing industry specification or federal or military standards for the material.

**A-Basis** properties = at least 99% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

### MATERIAL PROPERTIES: 30-Jun-97

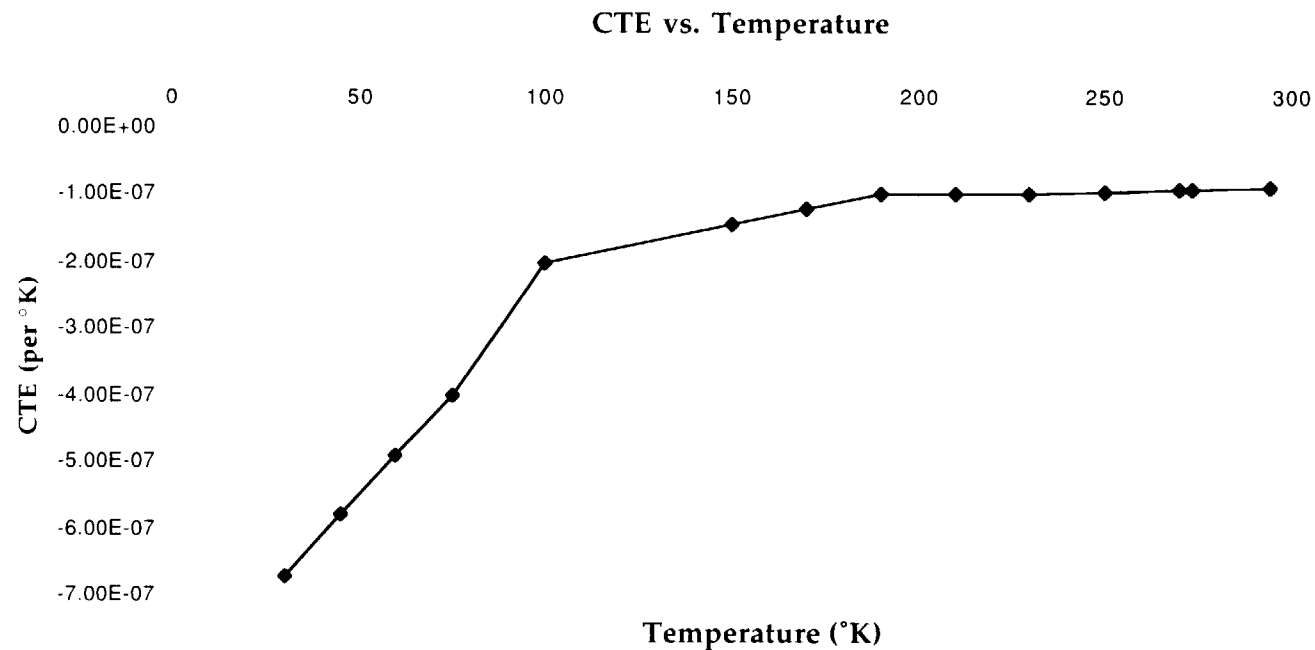
Direction =														
Basis =		Typical	Typical		Typical		Typical	Typical	Typical					
Type =														
Temperature		<u>Density</u>	<u>Ultimate Strength</u>	<u>Yield Strength</u>	<u>Elastic Modulus</u>	<u>Poisson's Ratio</u>	<u>Microyield Strength</u>	<u>CTE</u>	<u>Thermal Conductivity</u>	<u>Specific Heat</u>	<u>Radiative Absorptivity</u>	<u>Radiative Emmissivity</u>		
( °C )	( °K )	rho (kg/m^3)	UTS (MPa)	YTS (MPa)	E (GPa)	mu (—)		(per °K)	k (W/m-K)	Cp (J/kg-K)	alpha	epsilon		
-243 °C	30 °K	assumed 2530						about - 6.7E-7	0.2	about 50				
-228 °C	45 °K							int. - 5.8E-7	0.4	about 100				
-213 °C	60 °K							int. - 4.9E-7	0.6					
-198 °C	75 °K							about - 4.0E-7	0.7					
-173 °C	100 °K							about - 2.0E-7	0.9					
-123 °C	150 °K							88.3	int. - 1.4E-7					
-103 °C	170 °K							88.65	int. - 1.2E-7					
-83 °C	190 °K							89	about - 1.0E-7				about 500	
-63 °C	210 °K							89.3	about - 1.0E-7					
-43 °C	230 °K							89.6	int. - 9.8E-8					
-23 °C	250 °K							89.85	int. - 9.5E-8					
-3 °C	270 °K							90	int. - 9.3E-8					
0 °C	273 °K							90.05	int. - 9.3E-8					
21 °C	294 °K							90.3	0.243	-9.0E-8			1.46	800
600 °C	873 °K													

**FABRICATION:** Maximum = parts up to 8.2 m diameter and TBD thick.  
Minimum = somewhere in the ballpark of TBD.

**REFERENCES:** • Anon., "Zerodur - Precision from glass ceramics", Product brochure 10041, Schott Glass Technologies, Inc., Duryea, PA, date 10-91?

## CTE of Glass Ceramics Zerodur

The CTE is a calculated value, derived by taking the derivative of the measured thermal strain plot with respect to temperature.



Likewise, the test specimen's thermal strain from point T1 to point T2 can be calculated by integrating the CTE curve. This strain can then be divided by the change in temperature (T1–T2) to get an *average* CTE that can be used by analysts to simplify their thermal strain calculations for other structural configurations.

For NGST's temperature drop from 294 ° K to 30 ° K, the *average* CTE=0.208 E–6 per ° K.



# Material FIGURES OF MERIT: Structural & Thermal.

NASA MSFC. PD21 / Paul L. Luz

## Material: Glass Ceramics Zerodur

**SUPPLIER:** Schott Glass Technologies, Inc.      Contact = Bob Chamberlain  
400 York Avenue      (717) 457-7485 Ext. 305  
Duryea, PA 18642      (717) 457-6960

**BASIS** (as defined in "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5G, Department of Defense, November 1994, pp 1-8 to 1-9.):

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**B-Basis** properties = at least 90% of the population of values is expected to equal or exceed the material property allowable, with a statistical confidence of 95%.

**Typical** properties = average values with no statistical assurance associated with them.

### FIGURES OF MERIT: 30-Jun-97

Direction =						
Basis =		0	Typical			
Type =		Strength	Strength	Deflection	Thermal	Thermal
Temperature		Driven	Driven	Driven	Deform.	Deform.
		<b>Specific</b>	<b>Specific</b>	<b>Specific</b>	<b>Steady-state</b>	<b>Transient</b>
		<b><u>Strength</u></b>	<b><u>Strength</u></b>	<b><u>Stiffness</u></b>	<b><u>Distortion</u></b>	<b><u>Distortion</u></b>
(°C)	(°K)	UTS/rho	YTS/rho	E/rho	CTE/k	CTE-rho-Cp/k
		(kJ/kg)	(kJ/kg)	(MJ/kg)	(cm/MW)	E-6(sec/cm^2-K)
-243 °C	30 K				-335.00	-42.38
-228 °C	45 K				-145.00	
-213 °C	60 K				-81.67	
-198 °C	75 K				-57.14	
-173 °C	100 K				-22.22	
-123 °C	150 K					
-103 °C	170 K					
-83 °C	190 K					
-63 °C	210 K					
-43 °C	230 K					
-23 °C	250 K					
-3 °C	270 K					
0 °C	273 K					
21 °C	294 K			35.7	-6.16	-12.48
600 °C	873 K					
		^	^	^	^	^
		high	high	high	near zero	near zero
		is good	is good	is good	is good	is good

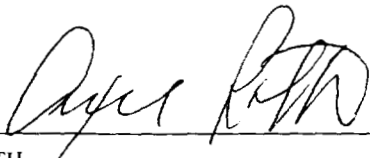


## APPROVAL

### **MIRROR MATERIAL PROPERTIES COMPILED FOR PRELIMINARY DESIGN OF THE NEXT GENERATION TELESCOPE (30 TO 294 KELVIN)**

P.L. Luz and T. Rice

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

A handwritten signature in black ink, appearing to read 'A. Roth', is written over a horizontal line.

A. ROTH  
DIRECTOR, PROGRAM DEVELOPMENT DIRECTORATE

<b>REPORT DOCUMENTATION PAGE</b>			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operation and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503				
1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE May 1998		3. REPORT TYPE AND DATES COVERED Technical Memorandum
4. TITLE AND SUBTITLE Mirror Material Properties Compiled for Preliminary Design of the Next Generation Space Telescope (30 to 294 Kelvin)			5. FUNDING NUMBERS	
6. AUTHORS P.L. Luz and T. Rice				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812			8. PERFORMING ORGANIZATION REPORT NUMBER  M-869	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NASA/TM-1998-208181	
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12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified-Unlimited Subject category 23 Nonstandard Distribution			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  This technical memorandum reports on the mirror material properties that were compiled by NASA Marshall Space Flight Center (MSFC) from April 1996 to June 1997 for preliminary design of the Next Generation Space Telescope (NGST) study. The NGST study began in February 1996, when the Program Development Directorate at NASA MSFC studied the feasibility of the NGST and developed the prephase A program for it. After finishing some initial studies and concepts development work on the NGST, MSFC's Program Development Directorate handed this work to the Observatory Projects Office at MSFC and then to NASA Goddard Space Flight Center (GSFC). This technical memorandum was written by MSFC's Preliminary Design Office and Materials and Processes Laboratory for the NGST Optical Telescope Assembly (OTA) team, in support of NASA GSFC. It contains material properties for 9 mirror substrate materials, using information from at least 6 industrial suppliers, 16 textbooks, 44 technical papers, and 130 technical abstracts.				
14. SUBJECT TERMS mirror materials, optical materials, mirror substrates, mirror material selection, structural design, thermal design, telescopes, optics.			15. NUMBER OF PAGES 44	
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17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	